

EFFECTS OF SOME AQUATIC
WEED CONTROL CHEMICALS ON
INVERTEBRATES AND PLANKTON IN
VERNON ARM OF OKANAGAN LAKE

by

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ABSTRACT

Application of bi-pyridylium and nitrile herbicides to 10 x 15 meter enclosures in Vernon Arm of Okanagan Lake did not adversely affect either community diversity or total numbers of aquatic invertebrates.

Numbers of invertebrates in the treated plots remained constant while numbers in the control plot increased during the 49 day sampling period. Continuing growth of aquatic plants provided suitable habitat for population expansions of herbivorous invertebrates primarily Diptera (Tendipedidae), Ephemeroptera, and Trichoptera. Changes in the dominant habitat from weed kill in treated plots may have prevented population increases during the post-treatment period.

Planktonic communities were also unaffected although changes in numbers of individuals were demonstrated. These changes were considered to be the result of seasonal variations rather than a delayed effect from herbicide treatment.

RESUME

L'application des herbicides de bi-pyridylum et de nitrile dans un enclos de 10 mètres sur 15 dans le bras Vernon du lac Okanagan, n'a pas diminué le nombre total des invertébrés aquatiques qui y vivaient et n'a pas nui à la diversité de leurs espèces.

Le nombre des invertébrés dans ces enclos traités est demeuré constant alors que dans les enceintes de contrôle leur nombre s'est accru pendant les 49 jours où les échantillons ont été recueillis. La croissance ininterrompue des plantes aquatiques offrait un milieu propice à la multiplication des invertébrés herbivores et surtout à celle des diptères (tendipedidae), des éphéméroptères et des trichoptères. Les changements apportés au milieu naturel par la destruction des herbes dans les enclos traités peuvent avoir empêché les invertébrés de s'y propager après l'application des herbicides.

Les communautés planctoniques sont également demeurées intactes sauf que la quantité de plancton a subi quelques changements. On a jugé que ces modifications étaient dues aux variations des conditions saisonnières et non à l'effet "à retardement" des herbicides.

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1. INTRODUCTION

The growth of luxuriant beds of Eurasian water-milfoil (Myriophyllum sp.) in Vernon Arm of Okanagan Lake has been a continuing source of public concern over the past three years. The beach areas along the northern and southern shores of Vernon Arm have been subject to increasing populations of weeds occupying an area of approximately 100 acres.

In May 1974, an experiment was initiated by the Water Investigations Branch of the British Columbia Department of Lands, Forests, and Water Resources to study the effectiveness of bi-pyridylum (diquat, paraquat) and nitrile (dichlobenil) herbicides for the control of Myriophyllum and other aquatic weeds in Vernon Arm. As members of the Aquatic Weed Committee, the Environmental Protection Service (EPS) agreed to monitor the impact of these herbicides on non-target macro-invertebrates and plankton. This report documents the results of the EPS investigations for the Aquatic Weed Committee chemical weed control experiment.

1.1 Literature Review

Recent field studies suggest that diquat and paraquat have little or no direct toxicity to bottom fauna and plankton at rates used for weed control (Calderbank, 1972; Way et al., 1971). However, changes in species diversity and numbers of aquatic invertebrates have been demonstrated following treatments with diquat (Hilsenhoff, 1966; Morton 1964; May et al. 1973). These authors reported that the abundance of herbivorous invertebrates decreased following chemical treatment while the density of detritus feeders increased.

Reduction in numbers following treatment have occurred over a period of one month or more with the greatest drop one or two weeks following treatment. Current knowledge of the impact of diquat and paraquat on benthic invertebrates and plankton indicate that harmful effects, when such exist, are temporary (Mullison, 1970; Morton, 1964).

Diquat and paraquat are very soluble in water and readily absorbed by aquatic weeds. Decomposition of the treated vegetation is

rapid and any residues remaining in the decomposed weeds are absorbed to the bottom mud and not released back into the water (Calderbank, 1972). Dichlobenil, applied as a granular formulation, is rapidly absorbed to the hydrosol and aquatic plants. However, because of the slow release from granular formulations, residues in water were still measurable after 188 days with the highest levels occurring about two weeks after treatment (Van Valin, 1966).

The concentration of these herbicides at the mud-water interface may be an important factor determining the effects of these chemicals on the benthic invertebrate fauna. Dichlobenil, which has been shown to form a strong layer at the bottom of laboratory test vessels, was reported to be more toxic with time to the bottom invertebrates (Wilson and Bond, 1969).

2 MATERIALS AND METHODS

2.1 Experimental Layout and Herbicide Application

The experiment was conducted at the north corner of Vernon Arm, Okanagan Lake (Figure 1). Four enclosures (indicated as Plots A to D in Figure 1) each 15 x 10 meters in size and approximately 30 meters apart, were located parallel to Kinsman Beach about 100 meters offshore. Each plot was surrounded by polyethylene sheets attached to nets to minimize the effects of dilution when testing the aquatic herbicides. The plastic and net barriers extended only about 0.9 meters down from the surface to permit fish to escape and reduce the chance of deoxygenation. Water depths ranged from 1.0 meters in May to 1.8 meters in July.

The following herbicides were applied on May 28, 1974 between 2000-2200 hours (concentration of chemicals is reported as parts per million of water):

Plot A: 1 ppmw diquat; 1 ppmw paraquat;
and 10 lbs./acre (approx. 0.6 ppmw)
dichlobenil

Plot B: 1 ppmw diquat; 1 ppmw paraquat

Plot C: 2 ppmw diquat

Plot D: Control

Solutions of diquat and paraquat were applied with a back-pack hand-pump sprayer with nozzle extending below the water surface. A granular formulation of dichlobenil was applied to Plot A.

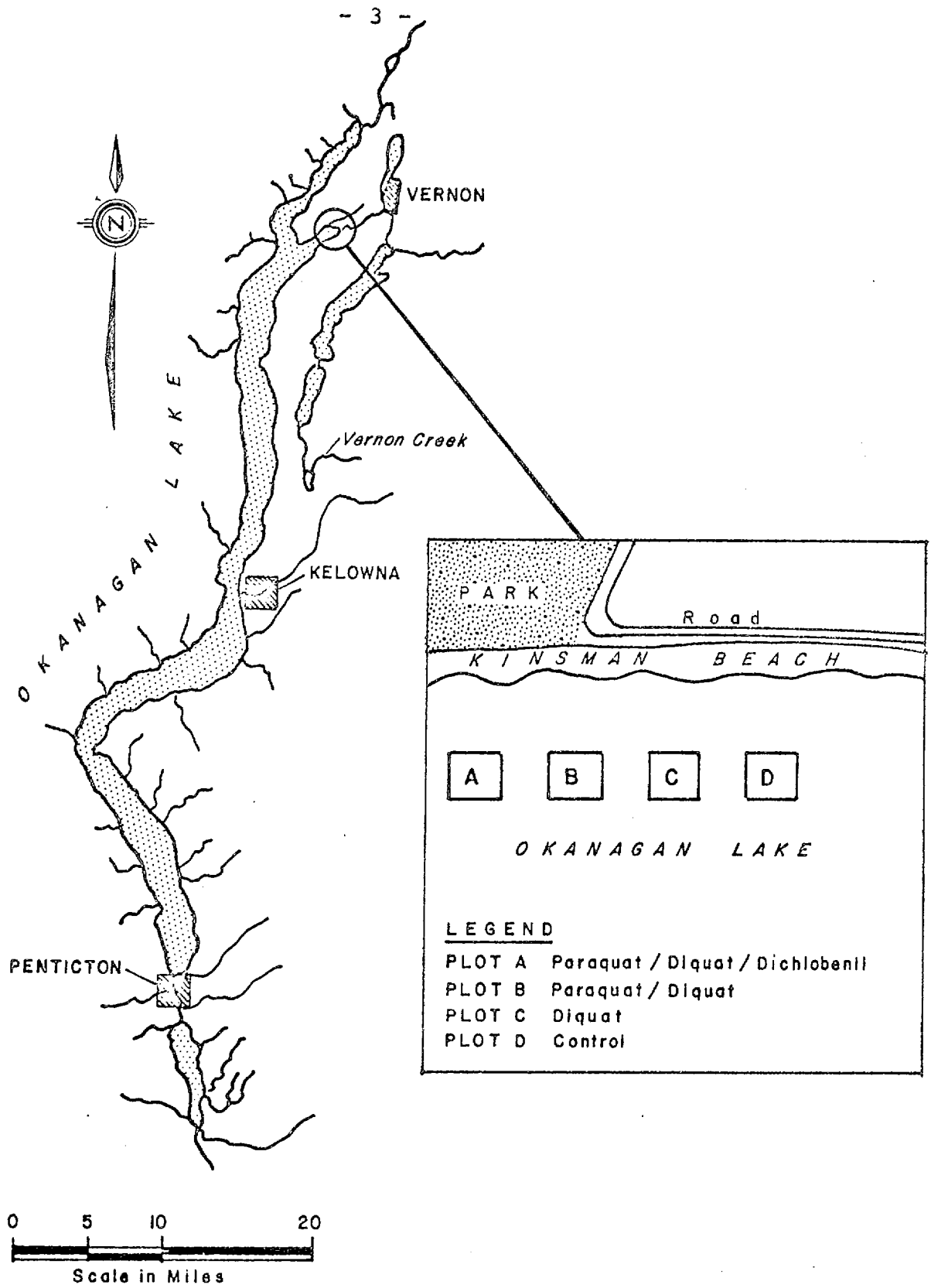


FIGURE 1. LOCATION OF VERNON ARM ON OKANAGAN LAKE SYSTEM AND SKETCH OF EXPERIMENTAL LAYOUT.

2.2 Sampling

An Ekman dredge (0.15 x 0.15 M²) was used to collect plant and mud samples. Triplicate grab samples were taken along a linear transect within each plot using a different transect during each sampling time. Care was taken not to sample half meter square quadrants cleared of plants by Water Investigations Branch personnel for biomass determinations. All samples were emptied into a 297-micron sieve and carefully washed to remove mud and silt from the plant material.

Periphytic and benthic invertebrates were collected by means of aspirators, retained in labelled bottles, and preserved in 50 per cent methanol. All samples were collected between 0800 and 1130 hours at each sampling time in order to circumvent diurnal effects.

Plankton samples were collected in a Wisconsin Plankton Net (diameter 0.25 M and mesh size 150 microns). The water column in each plot was sampled in triplicate with vertical hauls taken along the same transects as for Ekman sampling. Depths were measured for each haul. Planktonic samples were then preserved in 50 per cent methanol and all biological samples were retained for final separation, identification, and enumeration in the laboratory.

Samples were taken according to the following schedule:

<u>Days</u>	<u>Sampling Date (1974)</u>
14 Pre-treatment	May 14
7 " "	May 21
0 " "	May 28
1 Post-treatment	May 29
2 " "	May 30
7 " "	June 4
21 " "	June 18
35 " "	July 3

2.3 Sample and Data Analysis

Zooplankton, periphytic, and benthic invertebrates were identified to Order and phytoplankton to Genus. The following biological

keys were used: Edmondson (1959), Patrick and Reimer (1966), Pennak (1953), Prescott (1970), Usinger (1968), and Weber (1971).

Invertebrate samples were examined under a Wild M5 stereo microscope. The number of organisms in each major taxonomic group (family, order, class) was recorded. In the case of Oligochaeta, which were mostly fragmented, only segments having a head were considered.

Zooplankton organisms were enumerated by examining three one-ml aliquots of sample concentrate under a Wild M5 Stereo Microscope. The aliquots were pipetted into three separate counting chambers after the sample bottle had been agitated for 10-15 seconds. For examination of phytoplankton, a 10-ml aliquot of the sample concentrate was left to settle in glass covered counting chambers for 24 hours prior to examination. A wild M40 Inverted Compound Microscope was used for identification and enumeration. Two fields of 10 x 1 mm were counted per sample.

Statistical methods employed to evaluate biological response included two way analysis of variance, Duncan's multiple range test, diversity indices, and the Student's t statistic.

An index of diversity for communities of benthic and periphytic macroinvertebrates is an efficient and effective tool for quantifying the impact of organic pollutants on aquatic environments (Ramson and Dorris, 1972). The expression was first derived by Margalef (1956) from information theory and expanded by Wilhm and Dorris (1968) as:

$$\bar{d} = \sum_{c=1}^s \frac{n_i}{n} \log_2 \frac{n_i}{v}, \text{ where}$$

- \bar{d} = diversity per sample
- n_i = total number of individuals per taxon
- n = total number of individuals per sample
- s = total number of taxa

Diversity may be partitioned into two components:

- (a) species abundance or richness as represented by the number of taxa, and
- (b) evenness which is an index of distribution of individual organisms among species.

The "evenness" index (E), as described by Pielou (1967), is represented by the following function:

$$(e) = \frac{- \sum \frac{\eta_i}{n} \log \frac{\eta_i}{n}}{\log_5}$$

Diversity indices for aquatic invertebrates were calculated for each treatment using sampling time and number of organisms per taxa as variables. A Hewlett Packard Computer Model 9830 A (with automatic plotter) was employed for the (\bar{d}) and (E) calculations. Both values were computed to the Order level since classification above Order may not reveal significant herbicide effects.

Analysis of variance and Duncan's multiple range test were used to evaluate significant differences of both total and individual numbers of aquatic invertebrates and plankton between plots before and after treatment. These tests were also used to determine differences in \bar{d} values between plots. A Student's t statistic which adjusts for unequal sample sizes was used to evaluate differences in total numbers of invertebrates and plankton within each plot pre- and post- application.

3. RESULTS

3.1 Aquatic Macroinvertebrates

Macroinvertebrates found in Vernon Arm represented most of the major aquatic taxa: Annelida, Arachnida, Crustacea, Insecta, Gastropoda, and Pelecypoda. Numbers and kinds of invertebrates and collection dates are reported - Appendices I to IV. Diversity indices (\bar{d}) and evenness values (E) did not vary greatly among treatments or before and after herbicide application as illustrated in Figures 2-5 (actual data are shown in Appendix IX). Further, analysis of variance and Duncan's multiple

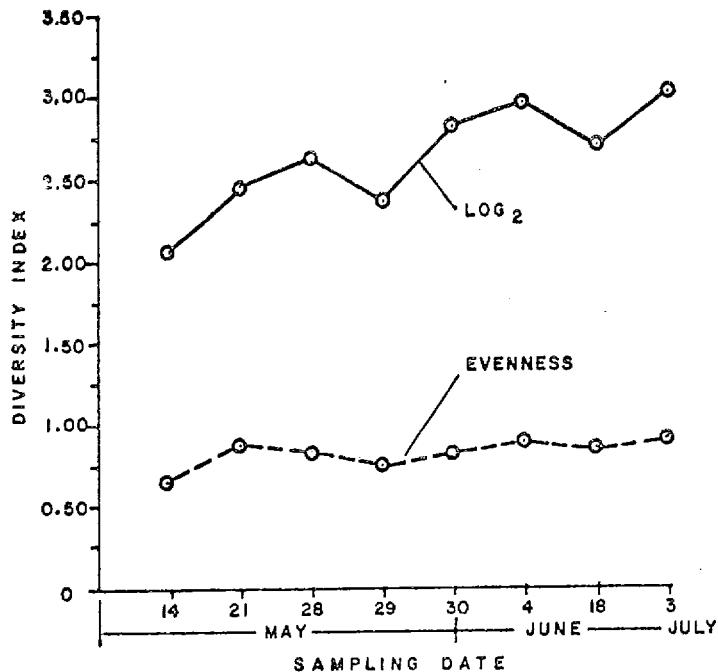


FIGURE 2 DIVERSITY INDICES AND EVENNESS VALUES OF AQUATIC INVERTEBRATES FOR PLOT A (PARAQUAT/DIQUAT/DICHLOBENIL)

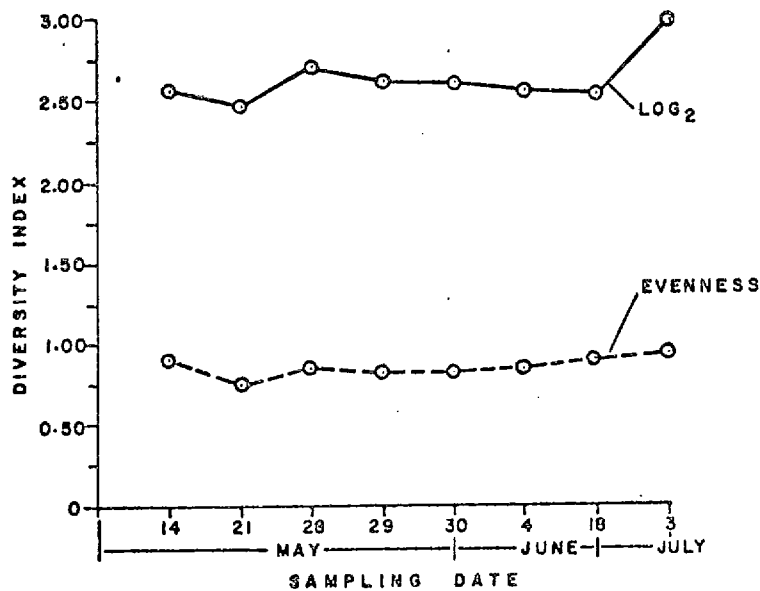


FIGURE 3 DIVERSITY INDICES AND EVENNESS VALUES OF AQUATIC INVERTEBRATES FOR PLOT B (PARAQUAT / DIQUAT)

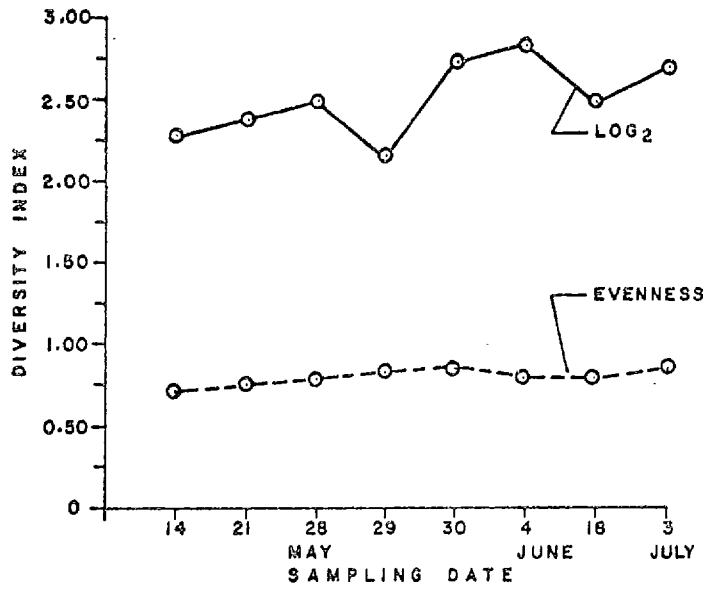


FIGURE 4 DIVERSITY INDICES AND EVENNESS VALUES OF AQUATIC INVERTEBRATES FOR PLOT C (DIQUAT)

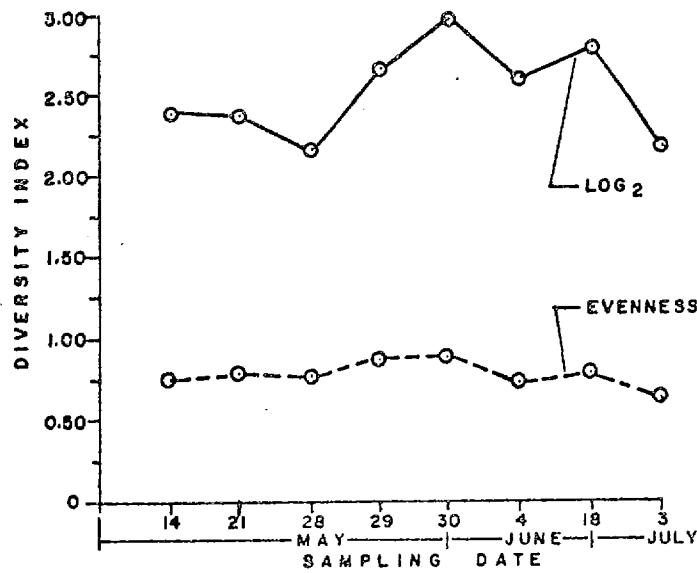


FIGURE 5 DIVERSITY INDICES AND EVENNESS VALUES OF AQUATIC INVERTEBRATES FOR PLOT D. (CONTROL)

range test at $p = .05$ did not indicate any significant difference in \bar{d} 's among the four plots. Therefore it would appear that the number of taxa remained constant with variations in the numbers of individuals accounting for the fluctuations in \bar{d} (Ransom and Dorris, 1972). "Evenness" values, which reflect the relative abundance and distribution of organisms among species, remained high. They ranged from 0.6 to 0.9 (maximum value = 1) suggesting even distribution of the aquatic fauna in the experimental areas.

Total numbers of the benthic and periphytic fauna were significantly lower post-application (Duncan's multiple range test at $p = .05$) in treatment plots A, B and C than in control plot D. Thus, an apparent population reduction in the treatment plots was indicated since there was no significant difference between any of the plots before treatment. However, further statistical evaluation showed no significant difference at the 0.05 probability level ($t_{df=6} = 1.943$) within each of Plots A, B, or C when comparing total invertebrate numbers pre- and post-application. A significant increase ($p = .05$) in numbers post-application was indicated for plot D ($t_{df=6} = 2.396$). Therefore, these results, as illustrated in Figure 6, suggest that total numbers remained constant in the treatment plots during the seven week sampling period; while during the post-treatment interval, numbers increased significantly in the control plot.

The same pattern was evident upon analysis of individual taxa although some groups pre-dominated over others. Numbers of each taxon in the treated plots remained largely constant (Tables 1 to 3) with increases in the control plot primarily due to changes in the numbers of Diptera (Tendipedidae), Ephemeroptera, and Trichoptera (Table 4). Although changes in numbers occurred for other taxa pre-versus post-spray (e.g., Hirudinea and Pelecypoda in plots A, C, and D; Trichoptera in plot B), the relative abundance of these organisms, as compared to other species in the same plot, remained low. Decreases in Amphipods were evident while at the same time increases in Tendipedidae occurred in all plots.

3.2 Phyto- and Zoo- Plankton

The phytoplankton community was represented by a variety of genera, but only four easily recognizable generic groups were counted: Asterionella spp., Cymbella spp., Fragilaria spp., and Synedra spp. The rest were enumerated but classified under Unidentified spp. The zooplankton consisted entirely of Cladocera and Copepoda. Numbers and kinds of plankton and collection dates are reported - Appendices V to VIII.

Total plankton numbers were significantly lower (Duncan's multiple range test at $p = .05$) after herbicide treatment in plots A, B, and C, than in control plot D as shown in Figure 7 and tabulated in Tables 5 to 8. This was also evident for numbers of Cymbella spp., Fragilaria spp., and the Unidentified spp., However, pre-application numbers of these species were consistently less in treatment plots with numbers of Cymbella spp. and Fragilaria spp. significantly less (at $p = .05$) in Plot A than in plot D and the Unidentified spp. significantly less in plots A and B than in plot D. Numbers of Synedra spp. and Asterionella spp. were not significantly different between any of the plots before or after herbicide treatment.

During the seven week sampling period, extensive changes in community structure occurred within each plot. In both treatment and control plots, unidentified phytoplankton species increased in numbers, while at the same time Asterionella spp., Cymbella spp., and Fragilaria spp. decreased (Appendices V to VIII). This was most pronounced in the case of Asterionella spp. which declined to negligible levels in the post-application period. Little effect on numbers of Cladocera or Copepoda was indicated.

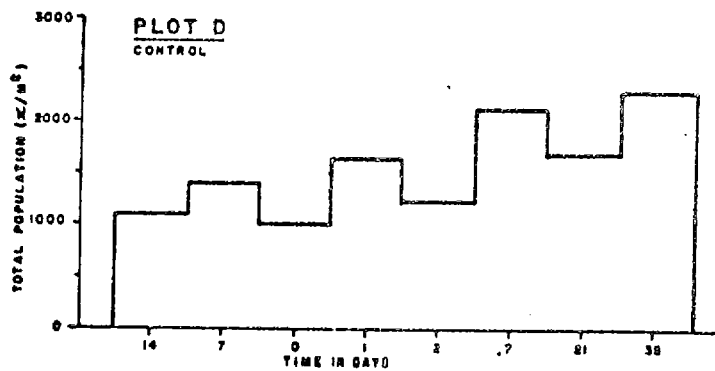
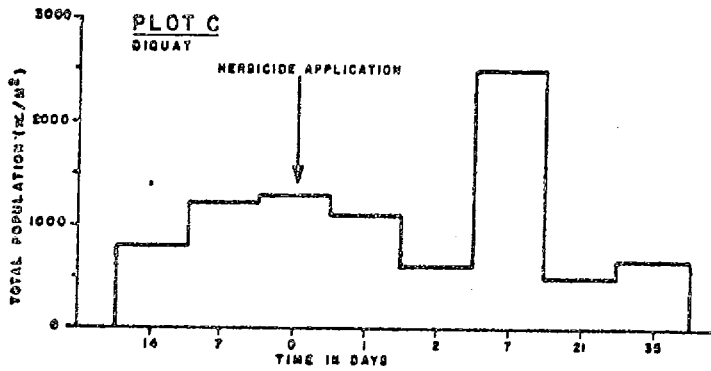
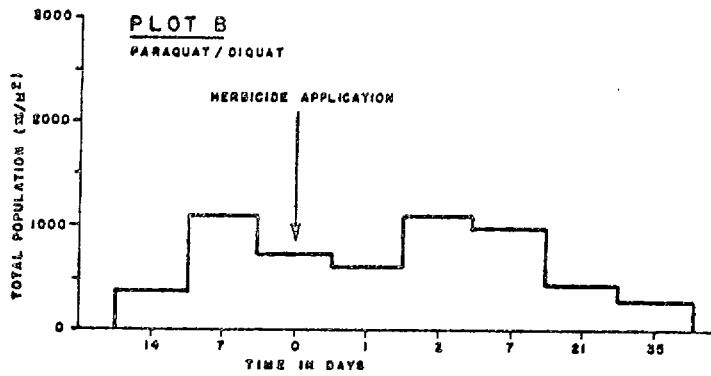
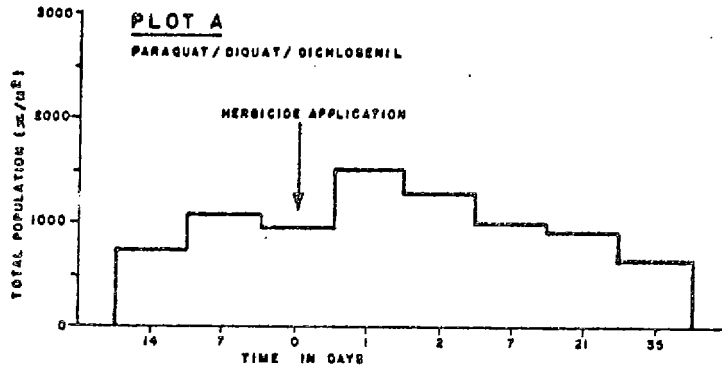


FIGURE 6 EFFECTS OF AQUATIC HERBICIDES ON TOTAL INVERTEBRATE NUMBERS

TABLE 1 CHANGES OF PERIPHYTIC AND BENTHIC POPULATIONS IN TREATED PLOT A (PARAQUAT/DIQUAT/DICHLOROBENIL)

Arthropoda ^a	Population (x/m ²)		Change ^b
	Pre-Spray (n=3) Mean ± S.E. (Range)	Post-Spray (n=5) Mean ± S.E. (Range)	
Amphipoda	340 ± 39 (301-402)	221 ± 118 (43-617)	0.65
Cladocera	10	0	-
Coleoptera	0	6	-
Diptera			
F. Tendipedidae	87 ± 53 (43-186)	171 ± 47 (72-272)	1.98
(Other Families)	0	12	-
Ephemeroptera	253 ± 66 (186-359)	258 ± 49 (115-358)	1.02
Gastropoda	43 ± 30 (0-86)	143 ± 16 (100-186)	3.33
Hirudinea	5 ± 5 (1-14)	54 ± 30 (14-158)	10.88
Hydracarina	5 ± 5 (0-14)	6 ± 3 (0-14)	1.12
Odonata			
Zygoptera	77 ± 29 (29-101)	75 ± 40 (0-158)	0.97
Oligochaeta	54 ± 27 (29-86)	40 ± 8 (29-57)	0.76
Pelecypoda	5 ± 5 (0-14)	52 ± 18 (14-115)	10.32
Trichoptera	53 ± 24 (14-72)	49 ± 10 (29-72)	0.92
TOTAL NUMBER	944	1087	1.15

- a - Immature and adult stages.
b - Change = $\frac{\text{post spray population}}{\text{pre-spray population}}$; >1 = increase, <1 = decrease
n - number of sampling times.

TABLE 2 CHANGES OF PERIPHYTIC AND BENTHIC POPULATIONS IN TREATED PLOT B (PARAQUAT/DIQUAT)

Arthropoda ^a	Population (x/m ²)		Change ^b
	Pre-Spray (n=3) Mean ± S.E. (Range)	Post-Spray (n=5) Mean ± S.E. (Range)	
Amphipoda	247 ± 129 (86-445)	158 ± 89 (0-430)	0.64
Cladocera	5 ± 5 (0-14)	3 ± 3 (0-14)	0.60
Coleoptera	0	0	-
Diptera			
F. Tendipedidae	105 ± 25 (72-143)	109 ± 32 (43-201)	1.04
(Other Families)	14 ± 14 (0-43)	20 ± 10 (0-43)	1.43
Ephemeroptera	134 ± 71 (43-243)	175 ± 68 (57-402)	1.31
Gastropoda	38 ± 16 (14-57)	26 ± 9 (29-43)	0.68
Hirudinea	0	6	-
Hydracarina	14 ± 10 (0-29)	9 ± 6 (14-29)	0.61
Odonata			
Zygoptera	124 ± 26 (86-158)	63 ± 30 (14-143)	0.51
Oligochaeta	19 ± 6 (14-29)	40 ± 9 (14-57)	2.11
Pelecypoda	19 ± 6 (0-43)	32 ± 11 (0-43)	1.66
Trichoptera	14 ± 10 (0-29)	49 ± 16 (29-100)	3.49
TOTAL NUMBER	728	690	0.95

See Table 1 for meaning of a, b and n

TABLE 3 CHANGES OF PERIPHYTIC AND BENTHIC POPULATIONS IN TREATED PLQT C (DIQUAT)

Arthropoda ^a	Population ($\times M^2$)		Change ^b
	Pre-Spray (n=3) Mean \pm S.E. (Range)	Post-Spray (n=5) Mean \pm S.E. (Range)	
Amphipoda	421 \pm 77 (301-516)	240 \pm 116 (14-631)	0.57
Cladocera	5 \pm 5 (0-14)	0	-
Coleoptera	0	3 \pm 3 (0-14)	-
Diptera			
F. Tendipedidae	77 \pm 26 (43-115)	158 \pm 63 (57-373)	2.05
(Other Families)	0	17 \pm 6 (0-29)	-
Ephemeroptera	177 \pm 96 (43-315)	258 \pm 98 (72-588)	1.46
Gastropoda	48 \pm 6 (43-57)	66 \pm 29 (0-157)	1.37
Hirudinea	5 \pm 5 (0-14)	12 \pm 8 (0-29)	2.32
Hydracarina	19 \pm 6 (14-29)	14 \pm 10 (0-43)	0.76
Odonata			
Zygotera	287 \pm 10 (273-301)	212 \pm 107 (14-531)	0.74
Oligochaeta	29 \pm 18 (0-43)	14 \pm 9 (0-43)	0.49
Pelecypoda	10 \pm 10 (0-29)	26 \pm 6 (14-43)	2.60
Trichoptera	53 \pm 39 (14-115)	83 \pm 32 (0-157)	1.57
TOTAL NUMBER	1131	1103	0.98

See Table 1 for Meaning of a, b and n

TABLE 4 CHANGES OF PERIPHYTIC AND BENTHIC POPULATIONS IN UNTREATED PLOT D (CONTROL)

Arthropoda ^a	Population ($\times M^2$)		Change ^b
	Pre-Spray (n=3) Mean \pm S.E. (Range)	Post-Spray (n=5) Mean \pm S.E. (Range)	
Amphipoda	497 \pm 76 (387-602)	275 \pm 48 (143-416)	0.55
Cladocera	0	52 \pm 16 (14-72)	-
Coleoptera	0	6 \pm 4 (0-14)	-
Diptera			
F. Tendipedidae	96 \pm 21 (72-129)	660 \pm 222(215-1391)	6.88
(Other Families)	0	31 \pm 12 (14-57)	-
Ephemeroptera	172 \pm 51 (100-243)	339 \pm 86 (158-559)	1.97
Gastropoda	71 \pm 46 (14-143)	95 \pm 25 (57-172)	1.34
Hirudinea	0	6 \pm 4 (0-14)	-
Hydracarina	19 \pm 16 (14-43)	17 \pm 9 (0-43)	0.91
Odonata			
Zygotera	262 \pm 35 (215-314)	209 \pm 38 (100-301)	0.80
Oligochaeta	29 \pm 18 (0-43)	43 \pm 16 (144-100)	1.48
Pelecypoda	9 \pm 6 (0-14)	26 \pm 9 (0-43)	2.87
Trichoptera	38 \pm 6 (29-43)	121 \pm 30 (43-201)	3.17
TOTAL NUMBER	1193	1880	1.58

See Table 1 for meaning of a, b and n

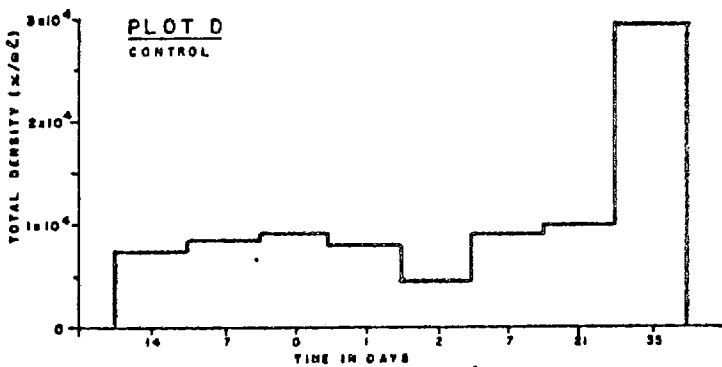
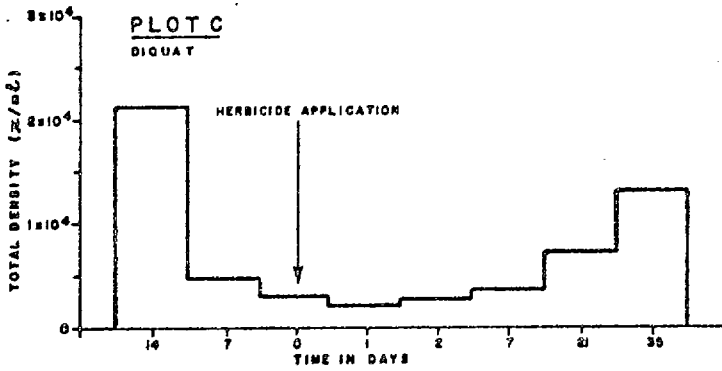
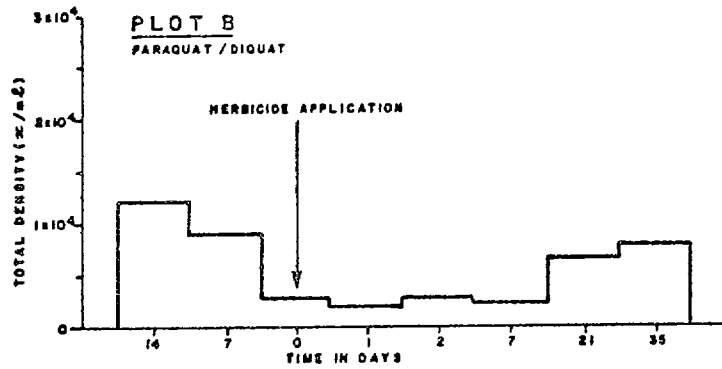
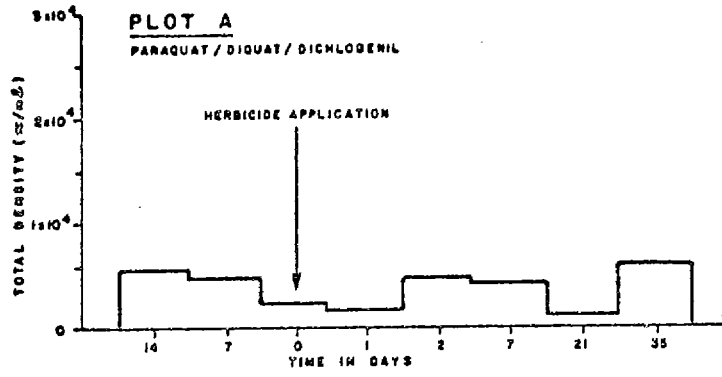


FIGURE 7 EFFECTS OF AQUATIC HERBICIDES ON TOTAL PLANKTON DENSITY

TABLE 5 CHANGES OF PLANKTONIC DENSITY IN TREATED PLOT A (PARAQUAT/DIQUAT/DICHLOROBENIL)

Plankton ^a	Density (x/ml)		Change ^b
	Pre-Spray (n=4) Mean ± S.E. (Range)	Post-Spray (n=6) Mean ± S.E. (Range)	
<u>Phytoplankton</u>			
<u>Asterionella</u> spp.	1507 ± 949 (196-3186)	74 ± 22 (0-147)	0.048
<u>Cymbella</u> spp.	308 ± 74 (147-392)	163 ± 61 (0-392)	0.785
<u>Fragilaria</u> spp.	490 ± 208 (343-637)	555 ± 104 (245-882)	1.133
<u>Synedra</u> spp.	98 ± 51 (0-196)	49 ± 20 (0-98)	0.500
<u>Unidentified</u> spp.	1654 ± 102 (1421-1813)	2736 ± 908 (833-5635)	1.654
(Total of all other groups)			
TOTAL NUMBER	3957	3577	0.903
<u>Zooplankton</u>			
Cladocera	5 ± 2 (107)	16 ± 3 (6-27)	3.133
Copepoda	19 ± 11 (4-46)	9 ± 2 (1-13)	0.473
TOTAL NUMBER	24	25	1.041

See Table 1 for meaning of a, b and n

TABLE 6 CHANGES OF PLANKTONIC DENSITY IN TREATED PLOT B (PARAQUAT/DIQUAT)

Plankton ^a	Density (x/ml)		Change ^b
	Pre-Spray (n=4) Mean ± S.E. (Range)	Post-Spray (n=6) Mean ± S.E. (Range)	
<u>Phytoplankton</u>			
<u>Asterionella</u> spp.	3614 ± 239 (147-8379)	25 ± 18 (0-98)	0.006
<u>Cymbella</u> spp.	343 ± 103 (147-539)	114 ± 11 (98-147)	0.333
<u>Fragilaria</u> spp.	980 ± 510 (343-1764)	294 ± 65 (147-539)	0.300
<u>Synedra</u> spp.	49 ± 0 (49-49)	41 ± 14 (0-98)	0.833
<u>Unidentified</u> spp.	2230 ± 602 (1617-3773)	3700 ± 1247 (1225-7889)	1.658
(Total of all other groups)			
TOTAL NUMBER	7216	4174	0.578
<u>Zooplankton</u>			
Cladocera	10 ± 4 (2-17)	30 ± 13 (8-83)	3.000
Copepoda	12 ± 8 (1-32)	5 ± 2 (1-10)	0.375
TOTAL NUMBER	22	35	1.590

See Table 1 for meaning of a, b and n

TABLE 7 CHANGES OF PLANKTONIC DENSITY IN TREATED PLOT C (DIOUAT)

Plankton ^a	Density (x/ml)		Change ^b
	Pre-Spray (n=4)	Post-Spray (n=6)	
	Mean ± S.E. (Range)	Mean ± S.E. (Range)	
<u>Phytoplankton</u>			
<u>Asterionella</u> spp.	4496 ± 4340 (49-15680)	49 ± 24 (0-147)	0.010
<u>Cymbella</u> spp.	294 ± 169 (147-735)	172 ± 30 (98-243)	0.583
<u>Fragilaria</u> spp.	915 ± 209 (637-1225)	286 ± 67 (98-490)	0.102
<u>Synedra</u> spp.	61 ± 36 (0-49)	49 ± 34 (0-196)	0.803
<u>Unidentified</u> spp.	2793 ± 1034 (1274-5390)	4802 ± 2002 (1127-12887)	1.719
(Total of all other groups)			
TOTAL NUMBER	8559	5358	0.643
<u>Zooplankton</u>			
Cladocera	16 ± 8 (5-34)	29 ± 10 (10-66)	1.822
Copepoda	12 ± 8 (2-32)	8 ± 2 (3-18)	0.680
TOTAL NUMBER	28	37	1.321

See Table 1 for meaning of a, b and n

TABLE 8 CHANGES OF PLANKTONIC DENSITY IN UNTREATED PLOT D (CONTROL)

Plankton ^a	Density (x/ml)		Change ^b
	Pre-Spray (n=4)	Post-Spray (n=6)	
	Mean ± S.E. (Range)	Mean ± S.E. (Range)	
<u>Phytoplankton</u>			
<u>Asterionella</u> spp.	1568 ± 1143 (0-4312)	32 ± 23 (0-98)	0.010
<u>Cymbella</u> spp.	564 ± 67 (441-490)	425 ± 144 (98-637)	0.752
<u>Fragilaria</u> spp.	3691 ± 1716 (1323-6174)	1225 ± 478 (392-3234)	0.331
<u>Synedra</u> spp.	110 ± 48 (0-196)	163 ± 87 (0-490)	1.484
<u>Unidentified</u> spp.	3761 ± 678 (2401-5194)	9734 ± 4330 (980-28224)	2.588
Total of all other groups)			
TOTAL NUMBER	9694	11,579	1.194
<u>Zooplankton</u>			
Cladocera	12 ± 4 (6-21)	20 ± 1 (15-22)	1.625
Copepoda	7 ± 3 (2-12)	14 ± 8 (5-10)	1.142
TOTAL NUMBER	19	34	1.789

See Table 1 for meaning of a, b and n

4. DISCUSSION

The results of this study indicate that no apparent adverse effect occurred on community diversity of aquatic invertebrates from any of the herbicide treatments. Further, no significant differences were evident in total numbers within treatment plots pre-versus post-application indicating little or no direct toxicity to the periphyton or bottom fauna. However, since numbers remained more or less constant in the treatment plots, changes in the dominant habitat may have prevented such natural increases in numbers of organisms in the treated plots as occurred in the control plot.

The population change in the control during June and July can be attributed primarily to the shift in the numbers of three invertebrate groups: a seven-fold increase in Diptera (Tendipedidae); a three-fold increase in Trichoptera; and a two-fold increase in numbers of Ephemeroptera. Small increases were also indicated for aquatic earthworms (Oligochaeta), snails (Gastropoda), and clams (Pelecypoda). Since all these taxonomic groups are herbivorous, the spectacular increase in weed growth which occurred in control plot D during June and July, may have provided a suitable habitat supporting this increase in macroinvertebrate numbers.

With the exception of Trichoptera which is omnivorous and Ephemeroptera which is almost entirely herbivorous, the other above groups feed on both higher plants or algae and organic detritus. Increased numbers of Tendipedidae, Oligochaeta, Gastropoda, and Pelecypoda in some treatment plots would tend to support the observation of Morton (1964) that weed kills are followed by increases in detritus feeders. Also, the depression of the Amphipod population in all the treatment plots post-application may indicate a certain sensitivity of these species to habitat alteration (Hilsenhoff, 1966), although comparable reductions were noted in the control plot.

The bi-pyridylium and nitrile herbicides did not appear to adversely affect planktonic organisms since total numbers within each plot remained unchanged during the seven week sampling period. In addition,

although planktonic numbers were consistently lower in the treatment plots than in the control plot, this occurred both before and after application. A shift in community structure (numbers per taxon) for both phytoplankton and zooplankton was demonstrated. However, since the plots were not closed systems but subject to exchange with the surrounding lake, it seems likely that changes in standing stocks during June and July were due more to seasonal cycles than from any delayed effect of herbicide treatment.

The larval and nymphal stages of many of the invertebrate taxa (e.g.: Tendipedidae, Ephemeroptera) are an important source of food for fish. (Pennak, 1953). In turn, many of these same invertebrates are herbivorous and feed on aquatic vegetation. Similarly, the zooplankters comprising the Cladocera and Copepoda, also important sources of fish food, "graze" upon the phytoplankton which itself may be destroyed by herbicides, especially in large scale applications or in confined areas such as ponds or small lakes.

5. CONCLUSIONS

No adverse short-term effects on aquatic invertebrate and Plankton communities could be demonstrated by application of bi-pyridylum and nitrile herbicides to experimental plots. However, these conclusions must be considered as preliminary because of the limitations inherent in this experiment including small plot size, water exchange with the surrounding lake, and lack of replication of treatments. These factors would, no doubt have some effects on the results, especially planktonic samples.

Future monitoring programs should be executed only on larger treatment areas to allow adequate measurement of direct and indirect effects on non-target organisms ranging from phytoplankton to fish. The importance of weed habitat to the fisheries in Vernon Arm must be established. This should include studies on identification, feeding, and reproduction of resident fish species relative to their dependence on the weed habitat and associated food organisms. Therefore, the major problem

is to what extent weed control will affect fish productivity by virtue of the destruction of habitat and food organisms.

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APPENDIX I: NUMBERS OF PERIPHYTIC AND BENTHIC INVERTEBRATES IN PLOT A (DIQUAT, PARAQUAT, DICHLOBENIL)

PLOT A (\times/M^2)	SAMPLING DATE					
	14/5	21/5	28/5	29/5	30/5	3/7
<u>Arachnida</u>						
Hydracarina	14	0	0	0	14	0
<u>Annelida</u>						
Hirudinea	14	0	1	29	14	158
Oligochaeta (All Fragments)	29	86	43	29	29	29
<u>Crustacea</u>						
Amphipoda	402	316	301	617	215	186
Cladocera	29	0	0	0	0	0
<u>Insecta</u>						
Coleoptera	0	0	0	0	0	14
Diptera						
F. Tendipedidae	43	72	186	272	272	100
(Other Families)	0	0	0	0	29	0
Ephemeroptera	186	359	215	358	315	201
Odonata						
Zygoptera	29	100	101	57	158	158
Trichoptera	14	72	72	72	29	72
Gastropoda	0	86	43	100	186	143
Pelecypoda (Pisidium)	0	0	14	14	43	43
TOTAL NUMBER	760	1091	976	1548	1304	988
						933
						659

APPENDIX II: NUMBERS OF PERIPHYTIC AND BENTHIC INVERTEBRATES IN PLOT B (DIQUAT, PARAQUAT)

PLOT B (x/M ²)	SAMPLING DATE							
	14/5	21/5	28/5	29/5	30/5	4/6	18/6	3/7
<u>Arachnida</u>								
Hydracarina	14	29	0	14	29	0	0	0
<u>Annelida</u>								
Hirudinea	0	0	0	0	0	0	0	29
Oligochaeta (All Fragments)	14	14	29	14	57	43	29	57
<u>Crustacea</u>								
Amphipoda	86	445	215	215	430	143	0	0
Cladocera	0	14	0	0	0	0	0	14
<u>Insecta</u>								
Coleoptera	0	0	0	0	0	0	0	0
Diptera								
F. Tendipedidae	72	100	143	129	201	115	57	43
(Other Families)	0	0	43	0	43	0	43	14
Ephemeroptera	43	243	115	86	172	402	158	57
Odonata								
Zygoptera	86	158	129	57	143	100	0	14
Trichoptera	0	29	14	29	29	100	57	29
<u>Gastropoda</u>	43	57	14	29	0	29	43	29
Pelecypoda (Pisidium)	0	14	43	29	43	57	29	0
TOTAL NUMBER	358	1103	745	602	1147	989	416	286

APPENDIX III: NUMBERS OF PERIPHYTIC AND BENTHIC INVERTEBRATES IN PLOT C (DIQUAT)

PLOT C (x/M ²)	SAMPLING DATE							
	14/5	21/5	28/5	29/5	30/5	18/6	3/7	
<u>Arachnida</u>								
Hydracarina	14	14	29	0	29	43	0	0
<u>Annelida</u>								
Hirudinea	14	0	0	0	0	29	0	29
Oligochaeta								
(All Fragments)	43	43	0	0	14	43	14	0
<u>Crustacea</u>								
Amphipoda	301	516	445	430	186	531	14	43
Cladocera	0	14	0	0	0	0	0	0
<u>Insecta</u>								
Coleoptera	0	0	0	0	0	14	0	0
Diptera								
F. Tendipedidae	43	115	72	158	86	373	57	115
(Other Families)	0	0	0	0	14	29	14	29
Ephemeroptera	43	172	315	158	72	588	229	244
Odonata								
Zygoptera	301	273	287	330	129	531	14	57
Trichoptera	14	29	115	0	43	157	86	129
Gastropoda	43	57	43	57	0	157	72	43
Pelecypoda (Pristidium)	0	0	29	14	29	43	29	14
TOTAL NUMBER	816	1233	1335	1147	602	2538	529	703

APPENDIX IV: NUMBERS OF PERIPHYTIC AND BENTHIC INVERTEBRATES IN PLOT D (CONTROL)

PLOT D (x/M ²)	SAMPLING DATE							
	14/5	21/5	28/5	29/5	30/5	4/6	18/6	3/7
<u>Arachnida</u>								
Hydracarina	14	43	0	14	0	29	43	0
<u>Annelida</u>								
Hirudinea	0	0	0	0	0	14	14	0
Oligochaeta (All Fragments)	43	43	0	100	43	43	14	14
<u>Crustacea</u>								
Amphipoda	502	602	387	273	272	416	143	272
Cladocera	0	0	0	0	14	0	43	72
<u>Insecta</u>								
Coleoptera	0	0	0	0	0	14	0	14
Diptera								
F. Tendipedidae	72	129	86	431	215	660	603	1391
(Other Families)	0	0	0	0	57	14	43	43
Ephemeroptera	100	243	172	372	172	559	431	158
Odonata								
Zygoptera	215	258	314	301	229	243	100	172
Trichoptera	29	43	43	43	100	101	201	158
Gastropoda	143	57	14	172	115	72	57	57
Pelecypoda (Pisidium)	14	0	14	0	43	14	43	29
TOTAL NUMBER	1132	1418	1030	1706	1260	2179	1735	2380

APPENDIX V: DENSITY OF PLANKTON IN PLOT A (DIQUAT, PARAQUAT, DICHLOBENIL)

PLOT A	SAMPLING TIME									
	14/5	21/5	28/5 (AM)	28/5 (PM)	29/5 (AM)	29/5 (PM)	30/5	4/6	18/6	3/7
<u>Phytoplankton (x/ml)</u>										
<u>Asterionella</u> spp.	3186	2646	196	0	98	98	147	49	49	0
<u>Cymbella</u> spp.	147	392	196	98	245	98	392	98	0	147
<u>Fragilaria</u> spp.	-	-	343	637	637	441	882	392	343	245
<u>Synedra</u> spp.	196	147	49	0	49	0	49	98	0	98
<u>Unidentified</u>	1813	1764	1617	1421	833	1078	3675	4165	1029	5635
(Total of all other groups)										
<u>Zooplankton (x/ml)</u>										
Cladocera	1	7	7	5	6	15	12	27	22	12
Copepoda	20	4	46	7	12	11	11	13	6	1
TOTAL NUMBER	5363	4960	2454	2168	1880	1741	5168	4842	1449	6138
			2311 (Mean)			1811 (Mean)				

APPENDIX VI: DENSITY OF PLANKTON IN PLOT B (DIQUAT, PARAQUAT)

PLOT B	SAMPLING TIME									
	14/5	21/5	28/5 (AM)	28/5 (PM)	29/5 (AM)	29/5 (PM)	30/5	4/6	18/6	3/7
<u>Phytoplankton (x/ml)</u>										
<u>Asterionella spp.</u>	8379	5782	147	147	0	98	0	49	0	0
<u>Cymbella spp.</u>	539	441	147	245	98	147	98	147	98	98
<u>Fragilaria spp.</u>	-	1764	343	833	392	245	539	196	147	245
<u>Synedra spp.</u>	49	49	49	49	49	98	49	49	0	49
<u>Unidentified</u>	3773	1568	1617	1960	1225	2058	2254	2205	6566	7889
(Total of all other groups)										
<u>Zooplankton (x/ml)</u>										
<u>Cladocera</u>	2	10	12	17	8	46	14	17	10	83
<u>Copepoda</u>	1	2	32	12	2	7	5	10	2	1
TOTAL NUMBER	12,743	9616	2347	3263	1774	2699	2959	2673	6823	8365

2805
(Mean)

2237
(Mean)

APPENDIX VII: DENSITY OF PLANKTON IN PLOT C (DIQUAT)

PLOT C	SAMPLING TIME									
	14/5	21/5	28/5 (AM)	28/5 (PM)	29/5 (AM)	29/5 (PM)	30/5	4/6	18/6	3/7
<u>Phytoplankton (x/ml)</u>										
<u>Asterionella spp.</u>	15,680	2107	49	147	147	49	49	49	0	0
<u>Cymbella spp.</u>	735	147	147	147	98	196	147	245	98	245
<u>Fragilaria spp.</u>	-	1225	882	637	441	245	490	196	98	294
<u>Synedra spp.</u>	49	147	49	0	49	49	0	0	0	196
<u>Unidentified (total of all other groups)</u>	5390	1274	2303	2205	1127	2107	2205	3381	7105	12,887
<u>Zooplankton (x/ml)</u>										
<u>Cladocera</u>	5	14	7	34	18	43	66	13	25	10
<u>Copepoda</u>	2	4	10	32	7	18	10	6	3	5
TOTAL NUMBER	21,861	4918	3447	3202	1887	2707	2967	3890	7329	13,637

3325
(Mean)

2297
(Mean)

APPENDIX VIII: DENSITY OF PLANKTON IN PLOT D (CONTROL)

PLOT D	SAMPLING TIME									
	14/5	21/5	28/5 (AM)	28/5 (PM)	29/5 (AM)	29/5 (PM)	30/5	4/6	18/6	3/7
<u>Phytoplankton (x/ml)</u>										
<u>Asterionella</u> spp.	1715	4312	245	0	0	98	98	0	0	0
<u>Cymbella</u> spp.	490	637	686	441	98	882	196	637	147	588
<u>Fragilaria</u> spp.	-	1323	6174	3577	686	3234	784	1617	392	637
<u>Synedra</u> spp.	196	0	98	147	0	147	49	294	0	490
<u>Unidentified</u> (Total of all other groups)	5194	2401	4067	3381	980	9604	3430	6517	9653	28,224
<u>Zooplankton (x/ml)</u>										
Cladocera	12	6	10	21	22	22	15	18	19	21
Copepoda	5	2	8	12	4	10	12	7	5	10
TOTAL NUMBER	7612	8681	11,288	7579	1790	13,997	4584	9090	10,216	29,970

9434
(Mean)

7894
(Mean)

APPENDIX IX: DIVERSITY AND EVENNESS VALUES OF AQUATIC INVERTEBRATES FOR PLOTS A, B, C, AND D AT DIFFERENT SAMPLING TIMES

Date of Sampling	Plot A $\frac{P(d)}{(d)} (E)$	Plot B $\frac{P(d)}{(d)} (E)$	Plot C $\frac{P(d)}{(d)} (E)$	Plot D $\frac{P(d)}{(d)} (E)$
May 14	2.078	2.558	2.263	2.388
May 21	2.457	2.465	2.373	2.369
May 28	2.634	2.703	2.486	2.145
May 29	2.372	2.615	2.130	2.649
May 30	2.834	2.594	2.714	2.965
June 4	2.968	2.545	2.825	2.586
June 18	2.707	2.528	2.476	2.775
July 3	3.018	2.984	2.686	2.156

Plot A - Paraquat/diquat/dichlobenil

Plot B - Paraquat/diquat

Plot C - Diquat

Plot D - Control